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Haberl, F., White, N. E., and Hallman, T. R. (1989). *Astrophys. J.* **343**, 409.
Hutchings, J. B. (1974). *Astrophys. J.* **192**, 677.
Jones, C., Forman, W., Tananbaum, H., et al. (1973). *Astrophys. J. Lett.* **181**, L43.
Kelley, R. L., Rappaport, S., Clark, G. W., and Petro, L. D. (1983). *Astrophys. J.* **268**, 790.
Khruzina, T. S. and Cherepashchuk, A. M. (1983). *Pis'ma Astron. Zh.* **9**, 144 [*Sov. Astron. Lett.* **9**, 78 (1983)].
Kudryavtsev, M. I. and Svertilov, S. I. (1991). *Pis'ma Astron. Zh.* **17**, 410 [*Sov. Astron. Lett.* **17**, 175 (1991)].
Lund, N. (1986). *X-Ray Instrumentation in Astronomy*, J. L. Culhane (ed.), Proc. SPIE Int. Soc. Opt. Eng., Vol. 597, p. 95.
Mertz, L. (1968). *Proc. Symp. Modern Optics*, Polytech. Inst. Brooklyn, p. 787.
Sazonov, S. Yu. et al. (1993). *Pis'ma Astron. Zh.* (in press).

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Observations of a cosmic gamma-ray burst on 23 July 1992 with the WATCH instrument on the *Granat* observatory

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The cosmic gamma-ray burst detected by the *Granat* observatory on 23 July 1992 at $20^h03^m08^s.377$ (UT) is one of the brightest events observed during its operation, beginning in December 1989. That burst was detected by three burst instruments on the observatory (PHEBUS, SIGMA, and WATCH). Below we give data from the WATCH Russian–Danish experiment on locating the source of the burst, the light curve in various energy ranges, and the evolution of the hardness of the radiation. We show that the source of the gamma-ray burst emitted a fading x-ray flux with a characteristic temperature $\sim$5 keV, in the approximation of a blackbody spectrum, for more than 40 sec after the burst ended in hard x rays. We give the limits on the luminosity of a steady source at the site of the burst in the 8–20 keV range. We show that the flux from a steady source at the site of the burst did not exceed 20 mCrab for at least several days before and after the event.

INTRODUCTION

The WATCH instrument, designed to monitor bright x-ray sources and observe x-ray transients, solar flares, and cosmic gamma-ray bursts, is part of the *Granat* space observatory. The *Granat* satellite was inserted into a high-apogee orbit on 1 December 1989. The instrument consists of four x-ray detectors, each of which has a rotating modulation collimator located above a mosaic scintillation crystal consisting of alternating bands of NaI(Tl) and CsI(Tl) crystal detectors. The energy range of the detected gamma rays is 8-180 keV. The geometrical area of the mosaic crystal is 48 cm^2. The instrument was developed and built at the Danish Space Research Institute. The instrument has been described in more detail by Lund (1992).

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LOCATION OF THE SOURCE

Thanks to the rotating collimator, the WATCH instrument can determine the coordinates of x-ray sources and bright cosmic gamma-ray bursts. The rotation rate of the modulation collimator is 1 rps. From the modulation pattern resulting from the integration of pulses during rotation of the collimator, one can uniquely determine the coordinates of a gamma-ray burst. To locate the source reliably, three conditions must be satisfied simultaneously: a) the gamma-ray burst must be sufficiently intense; b) the duration of the gamma-ray burst must exceed 1 sec; c) the light curve must be sufficiently smooth and contain no bright features lasting much less than 1 sec.

All of those conditions were satisfied for the event under consideration. The location of the source based on the WATCH data is given in Fig. 1. It coincides with the coordi-

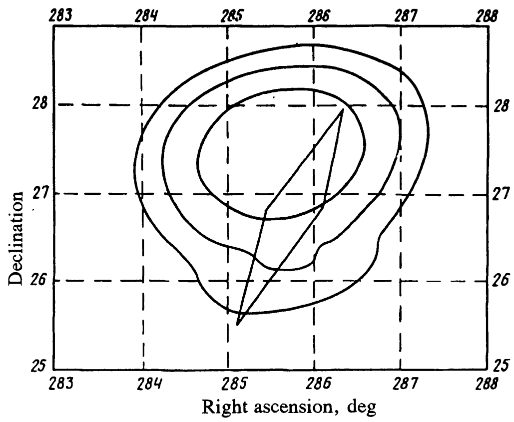

FIG. 1. Location of the source of the burst based on the SIGMA instrument (parallelogram: the contour corresponds to one standard deviation) and the WATCH instrument (the contours correspond to one, two, and three standard deviations).

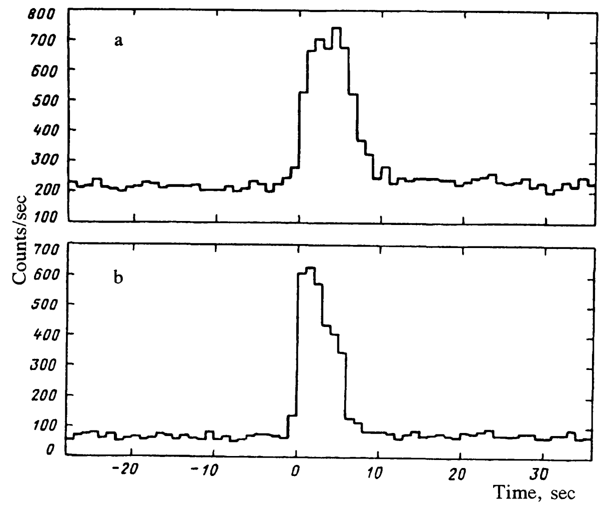

FIG. 2. Light curves of the source of the gamma-ray burst detected by the WATCH instrument in the 8-20 keV (a) and 20-60 keV (b) energy ranges.

nates obtained from the data of the SIGMA telescope, given in the same figure (Claret et al., 1992).

LIGHT CURVE

The WATCH instrument in the burst detection mode records the light curves of events with 1 sec time resolution. In WATCH's soft x-ray range (8-20 keV), this gamma-ray burst has a smooth light curve with no fine features (Fig. 2a). In the hard x-ray (20-60 keV, Fig. 2b), the intensity fades considerably faster following the maximum. The energy release of the burst in the 8-60 keV range was $(1.04 \pm 0.02)\cdot 10^{-5}$ erg/cm^2. The maximum energy flux in the same range is estimated to be $(1.9 \pm 0.1)\cdot 10^{-6}$ erg/(cm$^2\cdot$sec), which is ~ 50 times the flux from the Crab Nebula in the same range.

The behavior of the light curve of this burst measured by the PHEBUS instrument on the *Granat* observatory in the even harder range >100 keV differs from the WATCH measurements and has two fairly narrow intensity maxima [see Fig. 2 in the paper by Terekhov et al. (1993)]. The evolution of the hardness of the spectrum, defined as the ratio of the counts by the instrument in the 20-60 and 8-20 keV ranges, is given in Fig. 3, with the hardness of the spectrum of the Crab Nebula, measured in similar units, being ≈ 0.2. The spectrum is hardest at the start of the measured light curve and becomes softer in the course of the event. The hardness was observed to behave similarly in the well-known event of 1 August 1983 (Kuznetsov et al., 1986) and is typical of several other gamma-ray bursts (Yoshida et al., 1989).

An analysis of the data given in Fig. 4 shows that fading radiation from the source was detected for more than 40 sec after the burst. By ~ 40 sec after the start of the burst, the flux from the source had fallen to 0.8 ± 0.2 counts/(sec$\cdot$cm^2), which is only ≈ 1.2 times the flux from the Crab Nebula and corresponds to an energy flux $\sim 10^{-8}$ erg/(cm$^2\cdot$sec) in the 8-20 keV energy range. The flux after the burst maximum decays with a characteristic time ~ 30 sec. An estimate of the temperature of the energy spectrum, assuming that it can be approximated as blackbody emission, yields a characteristic temperature 4.8 ± 2.7 keV for the source at the 3σ confidence level. In the approximation of bremsstrahlung emission, the temperature is higher, naturally, and is close to 10 keV.

On the basis of data from the LILAS instrument on the *Phobos* interplanetary station (Syunyaev et al., 1990; Barat et al., 1992), it has been noted that the soft component of bursts lasts far longer than the hard component. According to data from the *Ginga* satellite, the sources of some gamma-ray bursts display afterglow in x rays for a long time (~ 100 sec). That emission has blackbody spectra with characteristic temperatures 1-2 keV (Yoshida et al., 1989).

LIMITS ON THE SOURCE'S STEADY LUMINOSITY

The observation of the source's light curve with a characteristic decay time (by a factor $e = 2.72$) that is ~ 10 times longer than the burst raises the question of the luminosity of the source of the burst in the steady state. The detection of radiation associated with the afterglow of the sources of gamma-ray bursts would provide important information about their nature. The problem of the limits on the steady luminosity of the sources of bursts has been discussed in a number of

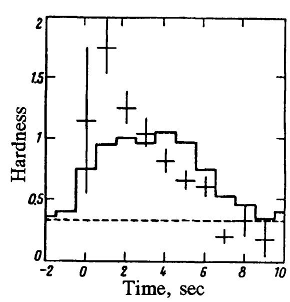

FIG. 3. Evolution of the hardness of the photon spectrum (crosses). The hardness is defined as the ratio of the numbers of photons detected in the 20-60 and 8-20 keV ranges. The light curve of the burst is given for comparison. The dashed line marks the background photon count rate.

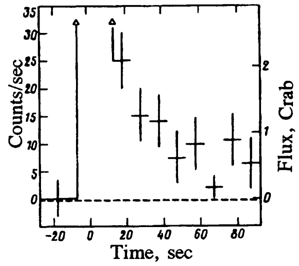

FIG. 4. Afterglow detected by the WATCH instrument in the 8-20 keV range after the end of the burst.

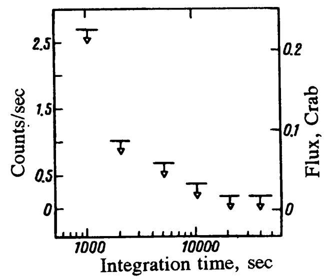

FIG. 5. Upper limits of sensitivity of the WATCH instrument as a function of the integration time of the modulation pattern.

papers (Pizzichini et al., 1986; Boer et al., 1988; Murakami et al., 1990). It is of interest in connection with the problem of the nature of the sources of gamma-ray bursts. Boer et al. (1988) and Pizzichini et al. (1986), on the basis of an analysis of data from the *Exosat* satellite and the *Einstein* observatory on the upper limits on the photon fluxes detected from the locations of gamma-ray bursts, have given limits on the accretion rate and temperature of the source at the site of the burst under the assumption that the source is an accreting binary system. Here it must be noted, however, that the *Exosat* observations used by them were made four or five years after the respective events were recorded, and the *Einstein* observations were made after intervals of from one month to two years.

The intensity of a source located at any point in the sky can be determined using the WATCH instrument. This advantage of the instrument enabled us to obtain limits on the source's intensity immediately after the burst, as well as before the event, by reconstructing the stored data. Unfortunately, the WATCH background and sensitivity in the observation of faint sources depend on the brightness of other sources in the field of view of the given detector of the instrument and contributing to the modulation pattern.

Using the modulation curves detected continuously during the observations, we can determine the flux from a source at the site of the burst. In the on-duty mode, each pattern is integrated for 1024 sec. The intensity of any steady source at the site of the burst, both before and after the burst, is below the WATCH sensitivity limit, which is given in Fig. 5. Note that the upper limit decreases with increasing integration time. Data from the instrument indicate that the source's luminosity did not exceed 20 mCrab for at least several days before and after the event.

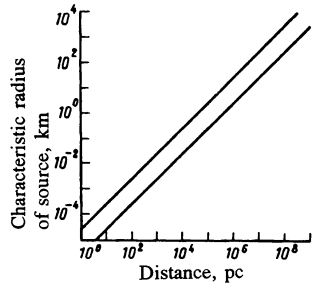

FIG. 6. Estimate of the characteristic linear size (radius) of the source of the gamma-ray burst as a function of its distance based on the detected afterglow in the 8-60 keV range. The upper limit corresponds to the minimum estimated temperature of the source (kT_{min} = 2.1 keV) at the 3σ level; the lower limit corresponds to the maximum estimate (kT_{max} = 7.5 keV) at the same confidence level.

A search for bright sources in the vicinity of the gamma-ray burst also showed an absence of any bright sources for at least several days before and after the event with upper limits close to those given in Fig. 5.

The above estimates of the temperature and luminosity of the source of the burst in the afterglow phase enable us to determine the possible size of the source of the afterglow. The result is given in Fig. 6, in which the allowed domain is the band between the two lines corresponding to the upper (7.5 keV) and lower (2.1 keV) limits of the temperature of the blackbody spectrum determined in the afterglow period. Assuming that the source lies at a certain distance, the upper and lower limits of its radius lie between the two lines in the figure. This estimate applies to all models of cosmic gamma-ray bursts from thermonuclear (Woosley and Walles, 1982; Hameury et al., 1982) to cosmological (Paczynski, 1990).

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Barat, C., Talon, R., Syunyaev (Sunyaev), R., et al. (1992). In: *Gamma-Ray Bursts Observations. Analyses and Theories*, E. E. Fenimore (ed.), University Press, Cambridge, p. 196.

Boer, M., Atteia, J. L., Gottardi, M., et al. (1988). *Astron. Astrophys.* **202**, 117.

Claret, A., Jourdain, E., Churazov, E., and Gilfanov, M. (1992). *IAU Circ.*, No. 5579.

Hameury, J. M., Bonazzola, S., Heyvaerts, J., and Ventura, J. (1982). *Astron. Astrophys.* **111**, 242.

Kuznetsov, A. V., Syunyaev, R. A., Terekhov, O. V., et al. (1986). *Pis'ma Astron. Zh.* **12**, 745 [*Sov. Astron. Lett.* **12**, (1986)].

Lund, N. (1992). In: *Gamma-Ray Bursts Observations. Analyses and Theories*, E. E. Fenimore (ed.), University Press, Cambridge, p. 188.

Murakami, T., Nishimura, J., Kawai, N., et al. (1990). *Astron. Astrophys.* **227**, 451.

Paczynski, B. (1990). *Astrophys. J.* **363**, 218.

Pizzichini, G., Atteia, J. L., Boer, M., et al. (1986). *Astrophys. J.* **301**, 641.

Syunyaev (Sunyaev), R., Arefiev, V., Borozdin, K., et al. (1990). In: *Proceedings of the 21st International Cosmic Ray Conference*, Vol. 12, p. 39.

Terekhov, O. V., Lobachev, V. A., Syunyaev, R. A, et al. (1993). *Pis'ma Astron. Zh.* (in press).

Woosley, S. E. and Walles, R. K. (1982). *Astrophys. J.* **258**, 716.

Yoshida, A., Murakami, T., Itoh, M., et al. (1989). *Publ. Astron. Soc. Jpn.* **41**, 509.

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Age of the stellar population in the nuclei of disk galaxies

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We have determined from observations with the 6-m telescope that strong Balmer absorption features are present in the spectra of the nuclei of 50% of early-type disk galaxies from SO to Sb. Using the method of evolutionary modeling of integrated spectra, we show that those nuclei contain a significant number of stars less than $5 \cdot 10^9$ years old. We have determined the metallicity for 21 disk galaxies with an old stellar population in their nuclei.

INTRODUCTION

It is rather difficult to separate the effects of age and metallicity on the basis of the integrated spectrum (or color) of a stellar system: a decrease in either one leads to bluing and to weakening of metal lines. In a two-color ($U - B$, $B - V$) diagram, for example, the color sequences of spiral galaxies with different current star formation rates approximately the solar chemical composition, and globular clusters in the Galaxy, which are old systems that differ mainly in metallicity, completely coincide. This paradox once caused a dispute about the nature of the blue color of the nuclei of Sc galaxies: McClure et al. (1980) stated that the nuclei of Sc galaxies resemble globular clusters in terms of the energy distribution in their spectra, and are therefore metal-poor, while O'Connell (1980), who specified *a priori* a solar chemical composition in his models, explained that blue color nicely by the youth of the stellar population. There have since been several successful attempts to separate the effects of metallicity and star formation in integrated spectra: Sil'chenko (1984) showed theoretically and Caldwell (1983) showed empirically that the lines of equal metallicity and equal age in the (Mg I 5175 Å, $B - V$) diagram have different slopes (and it turned out, incidentally, that intense star formation actually occurs in the nuclei of Sc galaxies), and Heckman (1980) and Rabin (1982) suggested that these effects be separated by comparing Balmer lines and the Mg Ib 5175 Å and Ca II 3933 Å metal lines.

Sil'chenko and Shapovalova (1989) and Sil'chenko (1990), in studying the spectra of the nuclei of nearby galaxies of different morphological types, discovered that whereas in elliptical galaxies only the Hβ line out of the entire Balmer series is present in absorption, the spectra of the nuclei of early-type disk galaxies, including S0 galaxies, are divided into two groups: *E* nuclei, whose spectra are similar to those of the nuclei of elliptical galaxies, and *H* nuclei, whose spectra contain appreciable Hγ and Hδ absorption lines. In Fig. 1 we give the distribution of the investigated elliptical, S0, and Sa−Sb galaxies by types *E* and *H*. We see that the overwhelming majority of elliptical galaxies have a type *E* spectrum, which can be completely described in terms of the model of an old stellar population with a near-solar metallicity. But 50% of early-type disk galaxies (here S0 galaxies do not differ at all from Sa−Sb galaxies) are of type *H*. Strong Balmer absorption features in the integrated spectrum can, in principle, be produced either by a stellar population of intermediate ages (10^8-10^9 years) and by an old stellar population with a low metallicity ($[m/\mathrm{H}] < -1$), where a considerable fraction of stars are on the blue horizontal branch. The present paper is devoted to determining the nature of the Balmer absorption features in the spectra of the nuclei of 50% of the nearby early-type disk galaxies.

INTERMEDIATE AGE OF THE STELLAR POPULATION OF *H* NUCLEI

In Fig. 2 we give a (⟨H⟩, Ca II K) diagram, in which the positions of *E* and *H* nuclei are compared with those of globular clusters in the Galaxy and evolutionary models with the solar chemical composition; the axes are mean equivalent width of Balmer absorption features and equivalent width of the Ca II K 3933 Å line.

Such a diagram was first used by Rabin (1982) to investigate clusters in the Magellanic Clouds. For the metallicity

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